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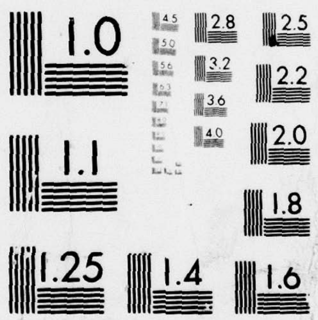
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SPUTTER DAMAGE IN GaAs EXPOSED TO LOW ENERGY ARGON IONS

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REPORT SF-26

SPUTTER DAMAGE IN GaAs EXPOSED TO LOW ENERGY ARGON IONS

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by

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and

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GaAs surfaces were exposed to Argon ion beams (50-500eV). When the beam energy exceeded 100 eV, they experienced degradation of Schottky barriers formed with evaporated gold. The depth of GaAs removal necessary for restoration of the barrier ranged from 20 to 50 Å with increasing ion beam energy.

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SPUTTER DAMAGE IN GaAs EXPOSED TO

LOW ENERGY ARGON IONS

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ABSTRACT

Substrates of n-type GaAs were exposed to charge neutralized argon ion beams of energy ranging from 50 to 500 eV. Exposure times were 10-30 minutes with a beam density of 1 ma/cm^2. 50 cm Schottky barrier diodes were formed on the sputtered surfaces using gold films. Capacitance and current measurements showed a marked decrease in barrier height for samples sputtered with energies > 150 eV, though rectification persists to higher beam energies. Chemical etching of the damaged layer to restore the Schottky barrier height showed that the characteristic depth of heavy damage was 20-50 A, increasing with ion beam energy.

<u>TEXT</u>

Deposition of insulating layers on gallium arsenide has been motivated both by the possibility of high-speed MISFET devices[1] and the need for encapsulating layers for post-implantation anneals.[2-4] It is desirable in either case to perform the deposition at temperatures below 500°C to prevent the loss of arsenic from the GaAs surface.[5] One promising technique, low energy ion-beam sputter deposition, seems to work best[6] when the GaAs surface is lightly sputter *in situ* etched prior to deposition. Such a procedure, however, raises the possibility of surface damage to the semiconducting material. The purpose of this paper is to study the effects, particularly the characteristic depth as far as the electronic properties are concerned, of such sputter etches.

Sputtering was done using a 2.5 cm Kaufman-type ion source.[7] Argon gas is introduced to a source chamber and ionized by a dc discharge. Positive argon ions are accelerated and the resulting beam neutralized with electrons from a hot filament. Beam energy was varied from 50 to 500 eV, and a beam current density of approximately 1 ma/cm^2 was maintained at all energies. Vacuum chamber pressure was 1×10^{-4} torr, and sputter times were 10, 20 or 30 minutes. Gallium arsenide samples used were <100> n-type material from Crystal Specialties, doped with tellurium to yield a carrier concentration of approximately 5×10^{18} cm^{-3}. Prior to sputtering, a gold-germanium back surface ohmic contact was formed using standard techniques. Individual samples, approximately 1 cm^2, were cleaned with detergent, acetone, methanol, xylene and Chemsol-z and mounted on a movable stage. The GaAs was first held

clear of the beam while the proper energy and current density were adjusted. This procedure also allowed additional degassing of the ion source without contamination of the sample surface. Actual sputtering was performed with the sample rotated so that the GaAs surface was normal to the ion beam.

Gold Schottky diodes formed before sputtering, after sputtering, and after chemical etch-back were characterized by capacitance-voltage (C-V) and current density-voltage (J-V) measurements. The C-V studies utilized an 1 MHz Boonton capacitance meter and a 10-second voltage sweep ranging from - 4 to + 0.5 volts. These data yielded C^{-2} vs V plots which were quite linear so long as the current flow was low. The Schottky barrier heights were determined from the voltage intercept of the extrapolation of these curves.[8,9] Depth dependence of the sputter damage was measured using a calibrated chemical etch. Calibration in this case was achieved by measuring step heights with a scanning electron microscope, plotting depth vs time, and extrapolating to small removal depths. It was found that the etch rate was always nearly constant and that a mixture of H_2SO_4 (1 part), H_2O_2 (2 parts), and H_2O (10^5 parts) led to a convenient etch rate of 17 Å/min. After etching, additional Schottky diodes were formed using the same procedure.

Figure 1 depicts the C-V barrier height as a function of the energy of the argon ions used in the sputtering. The unsputtered samples, plotted as sputter energy equal to zero, showed slightly higher values than the one reported by Mead and Spitzer.[10] The general trend of Fig. 1, as expected, is a decrease in barrier height with stronger sputtering energy. Samples sputtered above 300 eV exhibited large reverse currents,

thus making C-V measurements invalid in this region. There is, however, considerable sample-to-sample variation. There is also an apparent barrier enhancement for short, low energy sputtering (10 min., 50 eV). This enhancement is attributed to the formation of a thin p-type layer at the surface.[11] Similar effects have been observed in other Schottky diodes such as when silicon is implanted with the opposite type donor,[12] when aluminum is thermally-diffused into silicon,[13] and when GaAs is anodized and the oxide removed.[14]

At higher sputtering energies, in addition to the fall in barrier height, there is an increase in the surface trap density as revealed by the slope of the C-V data, and a deterioration of the diode quality factor in the J-V data. These results are consistent with a picture in whcih progressively larger numbers of damage states are tailing into the bandgap. At energies above 50 eV, there is no systematic dependence of the C-V and J-V measurements on sputter time, presumably because the sputter rate[15] is high enough to etch many times the damage depth during all exposure times studied.

The effect of etching the sputtered GaAs surface, forming new Schottky diodes, and remeasuring the barrier height is shown in Fig. 2. An etch of 17 Å was sufficient to restore the original barrier in the samples sputtered at 50 eV but had little effect on the higher energy sputtered samples. Thirty-five Å restored the barrier for all samples sputtered at 300 eV or less, and 50 Å was required for those up to 500 eV. Again, the sputter time did not appear to have a significant effect.

There are two technological implications in these results. The first is that the use of a sputter etch, the order of 500 eV for argon, may be a useful procedure in forming ohmic contacts to GaAs, and presumably on other semiconductors. Such ion beam pretreatment does not require elevated temperatures and would be compatible with other vacuum deposition processing steps. The second implication, and original motivation for these studies, is that it appears possible to use the ion beam for effective sputter etching without undue distortion of electronic properties. In previous work,[16] for example, a 10-minute sputter etch with 100 eV argon was effective in improving the adhesion of Si_3N_4 deposited on GaAs, implying there is at least a small window in sputter energy where there is a favorable tradeoff between etching and damage.

We would like to thank Wayne McKinley for assistance in sample preparation and the U. S. Office of Naval Research for financial support through Contract N00014-76-C-0976.

REFERENCES

1. WIEDER, H. H.: "Perspectives on III-V Compound MIS Structures," J. Vac. Sci. Technol. 1978, 15, pp. 1498-1506.

2. DONNELLY, J. P., LINDLEY, W. T. and HURWITZ, C. E.: "Silicon and Selenium Ion Implanted GaAs Reproducibility Annealed at Temperatures Up to 950°C," Appl. Phys. Lett. 1975, 27, pp. 41-43

3. LIDOW, A., GIBBONS, J. F. and MAGEE, T.: "A Double-Layered Encapsulant for Annealing Ion Implated GaAs Up to 1100°C," Appl. Phys. Lett. 1977, 31, pp. 158-161

4. EISEN, F. H., WELCH, B. M., MÜLLER, H., GAMO, K., INADA, T. AND MAYER, J. W.: "Tellurium Implantation in GaAs," Solid-St. Electron. 1977, 20, pp. 219-223

5. LUM, W. Y., WIEDER, H. H., KOSCHEL, W. H., BISHOP, S. G. and McCOMBE, B. D.: "Thermal Degradatin of Homoepitaxial GaAs Interfaces," Appl. Phys. Lett. 1977, 30, pp. 1-3

6. BIREY, H., PAK, S. and SITES, J. R.: "Photoluminescence of Gallium Arsenide Encapsulated with Aluminum Nitride and Silicon Nitride," Appl. Phys. Lett. 1979, 35, pp. 623-625

7. READER, P. D., and KAUFMANN, H. R.: "Optimization of an Electron Bombardment Ion Source for Ion Machining Applications," J. Vac. Sci. Technol. 1975, 12, pp. 1344-1347

8. GOODMAN, A. M.: "Metal-Semiconductor Barrier Height Measurement by the Differential Capacitance Method - One Carrier System," J. Appl. Phys. 1963, 34, pp. 329-338.

9. MEAD, C. A.: "Metal-Semiconductor Surface Barriers," Solid-St. Electron. 1966, 9, pp. 1023-1033.

10. MEAD, C. A. and SPITZER, W. G.: "Fermi Level Position at Metal-Semiconductor Interfaces," Phys. Rev. 1964, 134, pp. A713-A716

11. CROWELL, C. R.: "A Simplified Self-Consistent Model for Image Force and Interface Charge in Schottky Barriers," J. Vac. Sci. Technol. 1974, 11, pp. 951-957.

12. SHANNON, J. M.: "Increasing the Effective Height of a Schottky Barrier Using Low-Energy Ion Implantation," Appl. Phys. Lett. 1974, 25, pp. 75-79.

13. BASTERFIELD, J., SHANNON, J. M. and GILL, A.: "The Nature of Barrier Height Variations in Alloyed Al-Si Schottky Barrier Diodes," Solid-St. Electron. 1975, 18, pp. 290-291.

14. VARADARAJAN, S., LITTLEJOHN, M. A. and HAUSER, J. R.: "The Characterization of and a Proposed GaAs/Anodic Oxide Interface," Electr. Mat. Conf., Boulder, CO, 1979, unpublished.

15. COMAS, J. and COOPER, C. B.: "Sputtering Yields of Severl Semiconducting Compounds Under Argon Bombardment," J. Appl. Phys. 1966, 37, pp. 2820-2822.

16. BRADLEY, L. E. and SITES, J. R.: "Silicon Nitride Layers on Gallium Arsenide by Low-Energy Ion Beam Sputtering," J. Vac. Sci. Technol. 1979, 16, pp. 189-192.

FIGURE CAPTIONS

Figure 1. Barrier heights deduces from C-V results.

Figure 2. Depth of damage affecting Schottky barrier as a function of sputter energy.

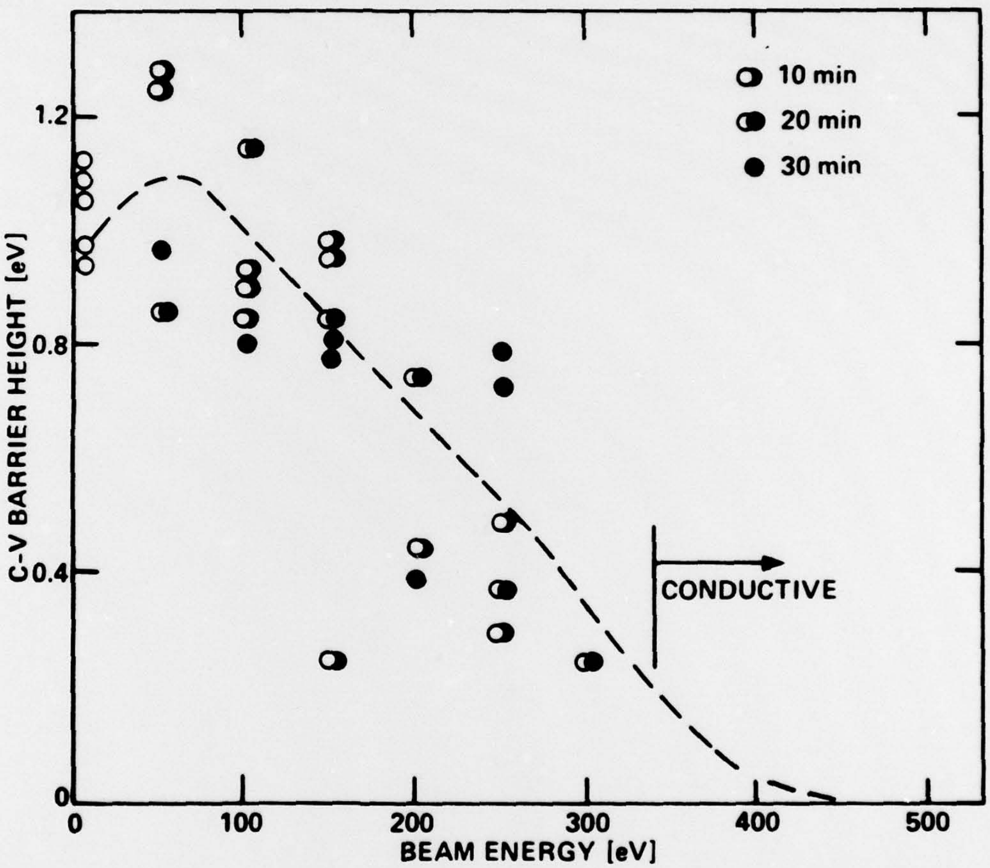
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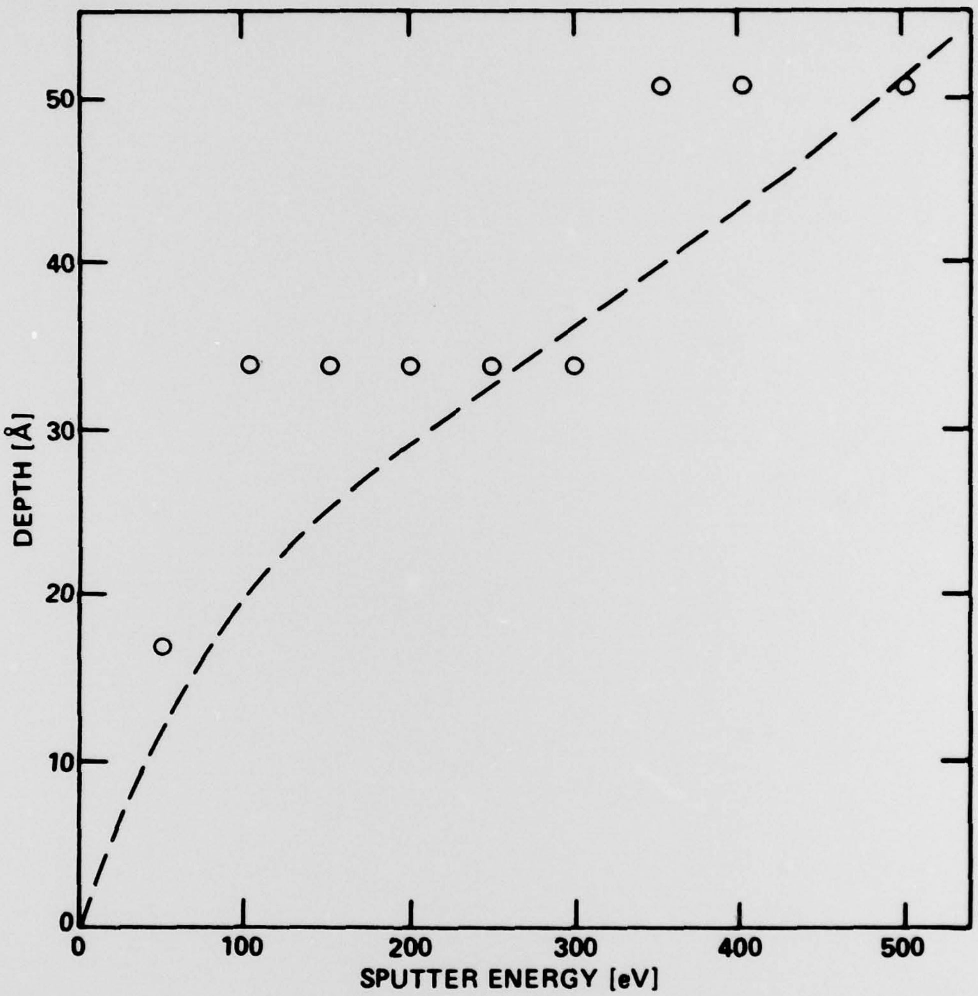
Fig. 1



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